

From the 750 GeV Diphoton Resonance to Multilepton Excesses

Kyu Jung Bae^a, Chuan-Ren Chen^b, Koichi Hamaguchi^{a,c} and Ian Low^{d,e}

^a*Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan*

^b*Department of Physics, National Taiwan Normal University, Taipei 116, Taiwan*

^c*Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU),
University of Tokyo, Kashiwa 277-8583, Japan*

^d*Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA*

^e*High Energy Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA*

Abstract

Weakly-coupled models for the 750 GeV diphoton resonance often invoke new particles carrying both color and/or electric charges to mediate loop-induced couplings of the resonance to two gluons and two photons. The new colored particles may not be stable and could decay into final states containing standard model particles. We consider an electroweak doublet of vector-like quarks (VLQs) carrying electric charges of 5/3 and 2/3, respectively, which mediate the loop-induced couplings of the 750 GeV resonance. If the VLQ has a mass at around 1 TeV, it naturally gives rise to the observed diphoton signal strength while all couplings remain perturbative up to a high scale. At the same time, if the charge-5/3 VLQ decays into final states containing top quark and W boson, it would contribute to the multilepton excesses observed in both Run 1 and Run 2 data. It is also possible to incorporate a dark matter candidate in the decay final states to explain the observed relic density.

I. INTRODUCTION

After the discovery of the 125 GeV Higgs boson at Run 1 of the Large Hadron Collider (LHC) [1, 2], the standard model (SM) of particle physics is now complete. However, SM is far from being perfect, since there is much empirical evidence pointing to its failures, ranging from the compelling case for cold dark matter to the baryon asymmetry in the universe. The evidence strongly calls for existence of physics beyond the SM (BSM).

Not surprisingly, there are many measurements exhibiting excesses over SM expectations at LHC Run 1. While some, or perhaps all, of the excesses may be statistical fluctuations, it is difficult to over-emphasize the importance of pursuing the theoretical implications of the first signs of BSM physics, which if remains true would be a discovery that is more profound and no less grand than that of the Higgs boson.

Among the Run 1 excesses, there is one which seems to persist in the early Run 2 results, showing up in searches for final states containing multilepton, b -jets, and missing transverse momentum (MET). The multilepton searches are often further divided into a same-sign dilepton (2L) category, a three-lepton (3L) category, and a four-lepton (4L) category. As was pointed out in Refs. [3, 4], the multilepton excesses were observed with varying degrees of significance in many Run 1 analyses in both ATLAS and CMS collaborations, which include searches for $t\bar{t}H$ production [5, 6], for scalar bottom quarks in supersymmetry [7, 8], for SM production of $t\bar{t}W$ [9, 10] and for heavy VLQs [11]. (The CMS Run 1 search for VLQ's, which imposes very hard cuts on the kinematics, is the only exception which didn't see an excess [12].) At Run 2, the multilepton excesses were seen by ATLAS in searches for scalar bottom quarks [13] and SM $t\bar{t}W$ production [14]. CMS, which collected 50% less “good” data than the ATLAS at Run 2 so far, sees a deficit in 2L channel and an excess in the 3L channel [15, 16].

The left panel of Fig. 1 summarizes the best-fit signal strength $\mu = \sigma/\sigma_{\text{SM}}$ in the $t\bar{t}H$ multilepton channel from the public Run 1 and Run 2 results, as well as a statistical combination of μ obtained from using the online script at Ref. [17], which is based on Ref. [18]. The resulting signal strength is $\mu = 2.4^{+0.8}_{-0.7}$ from combining both ATLAS and CMS Run 1/2 results.¹ In the right panel of Fig. 1 we display measurements of $\sigma(pp \rightarrow t\bar{t}W)$ from ATLAS,

¹ We have added an offset of -0.3 in the combined central value to take into account correlated systematic uncertainties. This procedure reproduces the individual central values from ATLAS and CMS, respec-

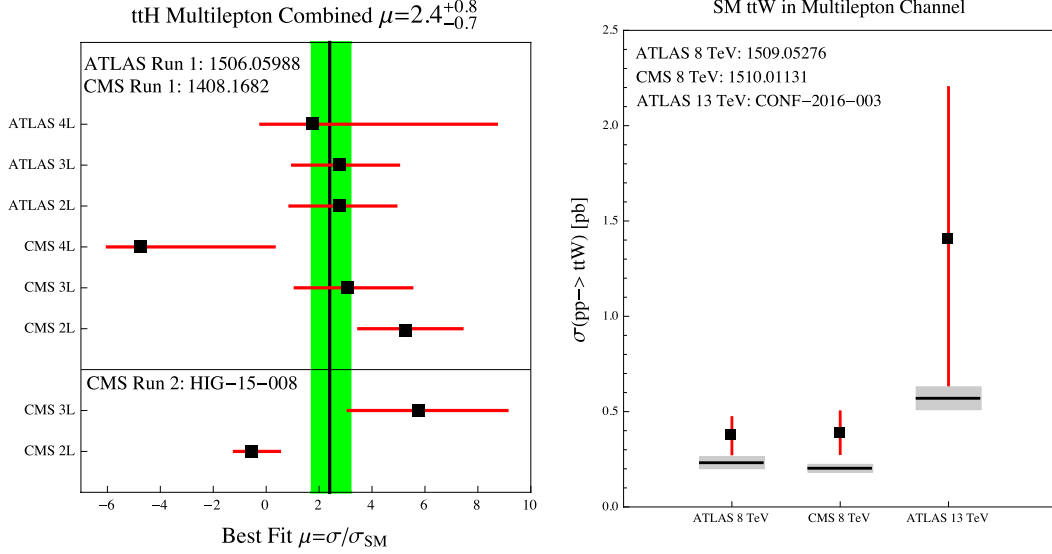


FIG. 1: *Left: Best-fit signal strength $\mu = \sigma/\sigma_{SM}$ in the ttH multilepton channel at both 8 TeV and 13 TeV LHC. Right: Measured $\sigma(pp \rightarrow ttW)$ in the multilepton channel at both 8 TeV and 13 TeV LHC. Shaded areas are the expected cross-sections with theoretical uncertainties.*

at both Run 1 and 2, and CMS at Run 1. The presence of excesses in the multilepton channel at both Run 1 and Run 2 is clear, although uncertainties in the measurements remain large. A number of works have theorized on the nature of these excesses [3, 4, 19, 20].

Nevertheless, the most significant sign of BSM physics in Run 2 undoubtedly comes from the observation of excessive events in the diphoton channel that are clustered at around an invariant mass of 750 GeV [21, 22]. Moreover, kinematic distributions of events in the signal region seem consistent with those expected from SM background [23], indicating single production of a resonance, with no or very soft extra particles, decaying into diphoton final states. On the other hand, compatibility with the null result from ATLAS Run 1 searches for a heavy resonance in the diphoton channel [24] prefers a production mechanism from the gluon initial states, due to the larger increase in the parton luminosity of the gluon.

If one further assumes the resonance is a spin-0 boson, then in weakly-coupled theories the neutral scalar couplings to massless gauge bosons such as the photon and the gluon are induced only at one-loop level by particles carrying QCD color and/or electric charges (see, for example, Ref. [25].) The particles in the loop, however, cannot be the SM particles, for

tively, with good precision.

it would immediately imply tree-level decays of the resonance into the SM particles, which in turn would swamp the loop-induced decays into diphotons and reduce the signal strength far below the observed ones. Therefore, in these scenarios additional new particles, other than the 750 GeV scalar itself, must be present. These new particles should carry color and/or electric charges and be heavier than 375 GeV so as to turn off the tree-level decay channel of the 750 GeV resonance. A popular possibility for the new particles mediating the loop-induced couplings is VLQ's carrying QCD color and electric charges [26–132].

There have been few discussions on the collider phenomenology of VLQs associated with the 750 GeV scalar [127–131], although VLQs have been proposed in other contexts, as partners of the third generation quarks in the SM [133, 134], which could decay into third generation quarks and W , Z , or the Higgs bosons. In this work we aim to demonstrate that, if the VLQ is an electroweak doublet with hypercharge 7/6, and has a mass at around 1 TeV, it could simultaneously explain the signal strength of the 750 GeV diphoton resonance and contribute to the aforementioned multilepton excesses associated with b -jets and MET. And the model could remain perturbative all the way up to a very high scale [131, 132].

This work is organized as follows: in the next section we demonstrate the connection between VLQs and the 750 GeV diphoton resonance, as well as the RG running of the relevant gauge and Yukawa couplings, which is followed by a Monte Carlo study on the contribution of the VLQs to the multilepton excesses at the LHC, using the $t\bar{t}H$ and $t\bar{t}W$ channels as examples. In the last section we conclude.

II. VECTOR-LIKE QUARKS AND DIPHOTON EXCESS

Assuming that the 750 GeV scalar S is produced by the gluon fusion, the diphoton signal rate is given by

$$\begin{aligned}\sigma(pp \rightarrow S \rightarrow \gamma\gamma) &\simeq \frac{C_{gg}}{s \cdot m_S} \frac{\Gamma(S \rightarrow \gamma\gamma)\Gamma(S \rightarrow gg)}{\Gamma_{S;\text{total}}} \\ &\simeq 6.4 \text{ fb} \times \left(\frac{\Gamma(S \rightarrow \gamma\gamma)}{1 \text{ MeV}} \right) \text{Br}(S \rightarrow gg)\end{aligned}\quad (1)$$

where $m_S \simeq 750$ GeV is the scalar mass, $\sqrt{s} = 13$ TeV and $C_{gg} = (\pi^2/8) \int_0^1 dx_1 \int_0^1 dx_2 \delta(x_1 x_2 - m_S^2/s) g(x_1) g(x_2)$ with $g(x)$ being the gluon parton distribution function. In the second equation, we have used $C_{gg} \simeq 2.1 \times 10^3$ which is obtained from MSTW2008 NLO

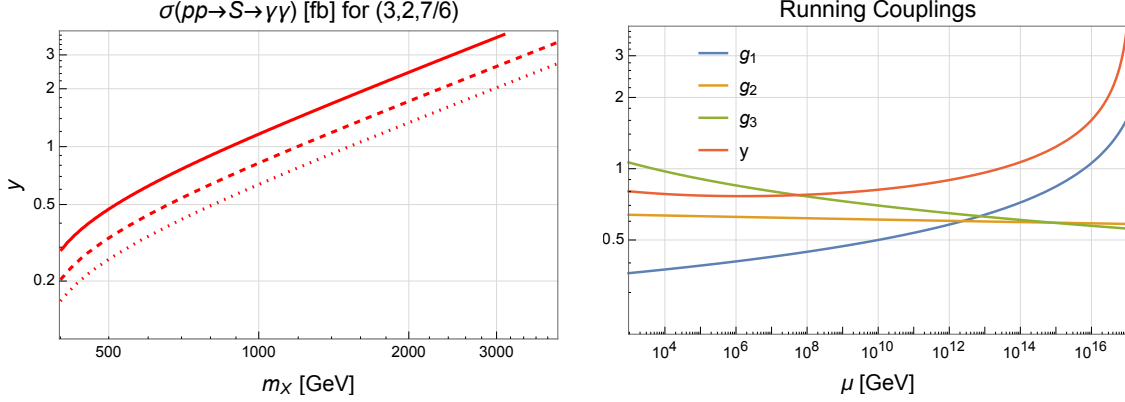


FIG. 2: *Left: contours of $\sigma(pp \rightarrow S \rightarrow \gamma\gamma)$ in (m_X, y) plane. Solid, dashed and dotted lines respectively show contours for 10, 5, 3 fb. Right: the running of the SM gauge couplings and the Yukawa coupling y for a benchmark point $m_X = 950$ GeV and $y = 0.8$.*

set [135] evaluated at the scale $\mu = m_S$. The reported signal strengths at Run 2 are somewhere between 1 and 10 fb [21, 22].

We assume that couplings of the scalar S to photons and gluons are induced by a VLQ X which transforms as $(\mathbf{3}, \mathbf{2}, 7/6)$ under $SU(3)_c \times SU(2)_L \times U(1)_Y$ of the SM gauge group:

$$-\mathcal{L}_{\text{int}} = y S \bar{X} i \gamma_5 X, \quad (2)$$

where S is assumed to be CP-odd.² Then, the partial decay width of S into the diphoton is given by

$$\begin{aligned} \Gamma(S \rightarrow \gamma\gamma) &= \frac{\alpha^2}{64\pi^3} m_S^3 \left[\frac{y}{m_X} \text{Tr}(Q^2) f(m_S^2/4m_X^2) \right]^2 \\ &\simeq 1.4 \text{ MeV} \times y^2 \left(\frac{1 \text{ TeV}}{m_X} \right)^2 f(m_S^2/4m_X^2) \end{aligned} \quad (3)$$

where $\text{Tr}(Q^2) = (5/3)^2 + (2/3)^2 = 29/3$ and the loop function is given by $f(\tau) = \tau^{-1} \arcsin^2 \sqrt{\tau}$ [136].

In Fig. 2, we show contours of $\sigma(pp \rightarrow S \rightarrow \gamma\gamma)$ in (m_X, y) plane. The observed diphoton signal rate can be obtained with $m_X \lesssim 1$ TeV and $y \lesssim \mathcal{O}(1)$. In the right panel of Fig. 2, the running of the SM gauge couplings and the Yukawa coupling y are shown for a benchmark point $m_X = 950$ GeV and $y = 0.8$, which leads to $\sigma(pp \rightarrow S \rightarrow \gamma\gamma) \simeq 5.4$ fb. As can be seen in the figure, the model remain perturbative up to about 10^{17} GeV.³

² In the case of CP-even S , the diphoton signal rate is suppressed by a factor of about 4/9.

³ If we add an additional VLQ T' , which is introduced in the model 3 discussed in the next section, the

Model S	Model 3
$S \text{ (1, 1)}_0$	$S \text{ (1, 1)}_0 \quad +$
$X \text{ (3, 2)}_{7/6}$	$X \text{ (3, 2)}_{7/6} \quad -$
	$T' \text{ (3, 1)}_{2/3} \quad -$
	$\phi \text{ (1, 1)}_0 \quad -$

TABLE I: *Matter contents of two simplified models. Model 3 contains a new parity under which the SM and S are even, while $X = (X_{5/3}, T)$, T' and ϕ are odd. ϕ is the lightest particle charged under the parity and could serve as a dark matter candidate ϕ .*

III. VECTOR-LIKE QUARKS AND MULTILEPTON EXCESS

The VLQ X , introduced in Sec. II to explain the diphoton excess, cannot be stable nor long-lived in order to avoid severe collider bound [137]. We will assume the lifetime of the VLQ is short enough to decay promptly inside the detector, when produced through QCD interactions at the LHC. Given the X carries SM quantum numbers, its decay product would include SM particles such as quarks and gauge bosons. In particular, if the charge-5/3 VLQ, $X_{5/3}$, decays into the top quark and the W boson, it could potentially contribute to the multilepton excesses observed at both Run 1 and Run 2 of the LHC.

We consider two simplified models in the spirit of minimality, one with a dark matter candidate and one without. Matter contents of both models are shown in Table. I. In the first model, Model S, the only new particles are the S and X which are introduced in Sec. II. We assume that the X field mainly couples to the third generation SM quark:

$$-\mathcal{L}_{\text{int}}^{\text{Model S}} = -\lambda(H \cdot \bar{X})t_R + h.c. + yS\bar{X}i\gamma_5 X. \quad (4)$$

where t_R is the right-handed SM top quark and $(H \cdot \bar{X}) = H^+\bar{X}_{5/3} + H^0\bar{T}$ with (H^+, H^0) and $(X_{5/3}, T)$ being the component fields of the $\text{SU}(2)_L$ doublets. In this setup, the decay chain of the VLQ $X_{5/3}$ is given by

$$X_{5/3} \rightarrow W^+ t \rightarrow W^+ W^+ b. \quad (5)$$

Therefore, pair-produced $X_{5/3}$ can lead to signatures containing multilepton, b -jets, and MET, where the MET comes from the neutrino in the W decay.

Landau pole of the $\text{U}(1)_Y$ coupling becomes slightly lower, about 10^{16} GeV.

In the second model containing the dark matter, Model 3, we introduce a singlet scalar dark matter field ϕ together with an additional VLQ, T' , and assign an odd parity to $X = (X_{5/3}, T)$, T' , and ϕ under a Z_2 parity to ensure the stability of the dark matter. The interaction is then given by⁴

$$-\mathcal{L}_{\text{int}}^{\text{Model 3}} = (H \cdot \bar{X})(\lambda + \lambda_5 \gamma^5)T' + y_\phi \phi \bar{T}' t_R + h.c. + yS \bar{X} i \gamma_5 X. \quad (6)$$

In the following, we assume $\lambda_5 = 0$, for simplicity. In this model the decay of $X_{5/3}$ leads to

$$X_{5/3} \rightarrow W^+ T' \rightarrow W^+ t \phi \rightarrow W^+ W^+ b \phi, \quad (7)$$

which again leads to the multilepton signal, with the additional MET contribution from the DM candidate ϕ . Furthermore, T' decays as follows

$$T' \rightarrow t + \phi, \quad (8)$$

therefore pair-production of T' at the LHC could lead to the final state $t\bar{t} + \text{MET}$. In the early universe, the dark matter ϕ could annihilate through the process $\phi\phi \rightarrow t\bar{t}$. In Fig. 3 we show the region of parameter space leading to the observed relic density of the dark matter in the $m_\phi - m_{T'}$ plane for some choices of y_ϕ .⁵ For numerical calculation, we generate model files using **FeynRules 2.3** [138] and obtain the relic density of dark matter using **micrOMEGAs 4.1.7** [139]. In addition, in this simple model the only SM particle that directly couples to the dark matter particle ϕ is the top quark. Therefore the direct detection constraint does not apply.

There are collider searches for $X_{5/3} \rightarrow tW^+$ at the LHC. In this channel the latest result from CMS using the early Run 2 data puts a lower bound $m_X \gtrsim 950$ GeV at the 95% confidence level (C.L.) [15], which would apply to the $X_{5/3}$ in Model S. In Model 3 $X_{5/3}$ decays into $tW^+\phi$ and the strong bound from CMS does not necessarily apply since the decay final state is different. The charge 2/3 component of the doublet, T , decays mainly to $t + Z/h$, and the current constraint is weaker than that of $X_{5/3}$ [140, 141]. For the electroweak singlet T' , no dedicated searches exist, although there exist searches for the scalar top quark (stop) in supersymmetry which also decays to $t\bar{t} + \text{MET}$. These limits,

⁴ The T' field can also have a coupling with S as $y'S\bar{T}'i\gamma_5 T'$, which slightly increases the diphoton rate.

⁵ The λ term in Eq. (6) induces a mixing between T' and T after electroweak symmetry breaking. We choose a small mixing, $\lambda = 0.01$ in Fig. 3.

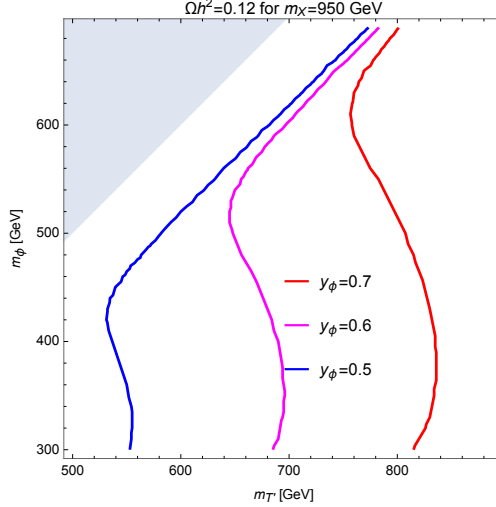


FIG. 3: *Region of parameter space of Model 3 leading to the observed dark matter relic density.*

however, are sensitive to a variety of kinematic variables including the mass of the particle carrying away the extra MET. In particular, constraints on direct stop productions in the $t\bar{t}$ +MET final states disappear when the LSP mass becomes larger than ~ 300 GeV [142–145]. Due to these considerations, we choose the following benchmark in our study

$$\text{Model S: } m_X = 950 \text{ GeV} , \quad (9)$$

$$\text{Model 3: } m_X = 950 \text{ GeV} , \quad m_{T'} = 750 \text{ GeV} , \quad m_{\phi} = 380 \text{ GeV} . \quad (10)$$

The choice of m_X in Model S maximizes the contribution to the multilepton excess without contradicting the limits from searches for $X_{5/3}$ at the LHC,⁶ while the value for m_{ϕ} is motivated not only by the stop constraints but also the need to turn off possible tree-level decay $S \rightarrow \phi\phi$,⁷ so as not to overwhelm the loop-induced decays into diphotons. $m_{T'}$ is then chosen to allow for on-shell W bosons and top quarks in the decay product.

In Table II we show the total signal strength, in unit of SM expectations, of our two benchmarks in the $t\bar{t}H$ and $t\bar{t}W$ channels at the LHC. In the Monte Carlo simulation we generate signal events using **Madgraph** [146] + **Pythia** [147] + **Delphes** [148] and a tagging efficiency of b -jet at 77%. In the $t\bar{t}H$ channel we implement the same cuts as in Ref. [4] at both 8 TeV and 13 TeV, and normalize the resulting events to the number expected from the

⁶ We emphasize that the CMS bound on $X_{5/3}$ from Ref. [15] does not apply to our Model 3. However, we choose the same m_X in both models for simplicity.

⁷ Such a decay could arise from the interaction $S\phi\phi$, which is irrelevant for our study for $m_{\phi} \geq m_S/2$.

	8 TeV μ_{ttH}	13 TeV μ_{ttH}	13 TeV μ_{ttW}
Model S	1.5	3.1	1.3
Model 3	1.4	2.9	1.3

TABLE II: *Total signal strengths, normalized to the SM expectations, of our benchmark models in ttH channel at both 8 TeV and 13 TeV and in ttW channel at 13 TeV. The mass spectrum is $m_X = 950$ GeV, $m_{T'} = 750$ GeV and $m_\phi = 380$ GeV.*

SM ttH production. In the ttW channel we base our selection cuts on those in the Section 5.1 of Ref. [14] in the same-sign di-muon channel. The total signal strength is then the sum of the SM expectation and the contribution from the $X_{5/3}$ VLQ,

$$\mu \equiv \frac{\sigma_{\text{SM}} + \sigma_{\text{VLQ}}}{\sigma_{\text{SM}}} = 1 + \mu_{\text{VLQ}} , \quad (11)$$

which is shown in Table II. For comparison, we note that the 95% C.L. upper limit in the ttH multilepton channel from CMS Run 2 data is [15]

$$\mu_{\text{ttH}} < 3.3 \text{ (2.6 expected)} \quad \text{at 95\% C. L.} \quad (12)$$

We see that both benchmarks give good fits to the multilepton excesses observed at both Run 1 and Run 2.

In the future, should the multilepton excess persist, it would be crucial to understand the nature of the excess. In this regard, we compare some kinematic distributions of events in the same-sign di-muon channel from our benchmark models with those from SM ttW in Fig. 4. In particular, we plot p_T of the leading jet and the leading muon, respectively, as well as the MET distribution. It is clear that events from our benchmarks in general have harder decay spectra than those from the SM.

Fig. 4 also highlights the importance of conducting dedicated searches for VLQs whose decay product contains a dark matter candidate carrying away extra MET, as the kinematic distributions are quite different between the two benchmarks. Such searches have not been performed at the LHC to the best of our knowledge. Although the MET distribution for Model 3 is harder than Model S, p_T distributions of the leading jet and the leading muon are softer in Model 3. Therefore we expect the selection efficiency will be different between the two benchmarks.

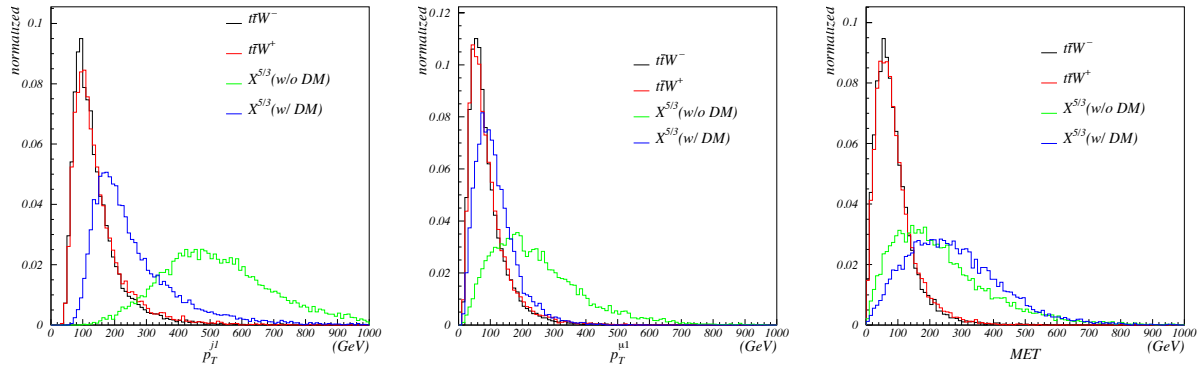


FIG. 4: From left to right: distributions of p_T of the leading jet, p_T of the leading muon, and MET for events from our Model S ($X_{5/3}$ without the dark matter), Model 3 ($X_{5/3}$ with the dark matter), and SM ttW .

IV. CONCLUSION

In this work we studied the LHC phenomenology of the VLQ that is often invoked to mediate loop-induced couplings of the 750 GeV diphoton resonance. In particular, we considered an electroweak doublet VLQ with hypercharge 7/6, giving rise to an exotic charge-5/3 VLQ and a top-like VLQ with charge-2/3. When the mass of the VLQ is at around 1 TeV, the desired diphoton signal strength can be obtained for a Yukawa coupling $y \lesssim \mathcal{O}(1)$. In this scenario, all gauge couplings as well as the VLQ Yukawa coupling remain perturbative up to a very high energy scale, of the order of 10^{17} GeV.

Decay phenomenology of the VLQ is quite distinct at the LHC, especially if they decay into the third generation fermions and the SM gauge bosons. For example, the charge-5/3 VLQ, $X_{5/3}$, could decay into a top quark and a W^+ boson. Alternatively, it is possible to include a stable neutral particle as the dark matter candidate with the correct relic density. Then the VLQ always decays into SM particles and the dark matter particle, which carries away additional MET in the collider detectors. Interestingly, we demonstrated that decays of $X_{5/3}$ could contribute to the mild excess in the multilepton, b -jets, and MET channel that are observed at both Run 1 and Run 2 of the LHC.

We performed numerical studies on two benchmark models, one with the dark matter particle and one without, and compared their kinematic distributions with those from the SM ttW processes. Should the multilepton excess persists in the future, such comparisons

will shed light on the nature of the excess. Furthermore, we showed that kinematic distributions between the two benchmarks are quite distinct, calling out the need for dedicated experimental efforts to search for a new decay topology of VLQs, into final states containing a dark matter candidate.

Acknowledgement

The authors are grateful to the workshop “Beyond the Standard Model in Okinawa 2016,” March 1 - 8, 2016, OIST, Okinawa, Japan, where this work was initiated. I. L. acknowledges helpful discussions with Bill Murray and the hospitality of KITP in Santa Barbara, which is supported by the National Science Foundation under Grant No. NSF PHY11-25915. This work was supported in part by Grant-in-Aid for Scientific research (Nos. 26104001, 26104009, 26247038, 26800123, 16H02189), World Premier International Research Center Initiative (WPI Initiative), MEXT, Japan, the U. S. Department of Energy under contracts No. DE-AC02-06CH11357 and No. DE-SC 0010143, and the National Science Council of R.O.C. under Grants No. NSC 102-2112-M-003-001-MY3.

-
- [1] **ATLAS** Collaboration, G. Aad *et al.*, “Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC,” *Phys. Lett.* **B716** (2012) 1–29, [arXiv:1207.7214 \[hep-ex\]](#).
 - [2] **CMS** Collaboration, S. Chatrchyan *et al.*, “Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC,” *Phys. Lett.* **B716** (2012) 30–61, [arXiv:1207.7235 \[hep-ex\]](#).
 - [3] P. Huang, A. Ismail, I. Low, and C. E. M. Wagner, “Same-Sign Dilepton Excesses and Light Top Squarks,” *Phys. Rev.* **D92** no. 7, (2015) 075035, [arXiv:1507.01601 \[hep-ph\]](#).
 - [4] C.-R. Chen, H.-C. Cheng, and I. Low, “Same-Sign Dilepton Excesses and Vector-like Quarks,” *JHEP* **03** (2016) 098, [arXiv:1511.01452 \[hep-ph\]](#).
 - [5] **ATLAS** Collaboration, G. Aad *et al.*, “Search for the associated production of the Higgs boson with a top quark pair in multilepton final states with the ATLAS detector,” *Phys. Lett.* **B749** (2015) 519–541, [arXiv:1506.05988 \[hep-ex\]](#).

- [6] **CMS** Collaboration, V. Khachatryan *et al.*, “Search for the associated production of the Higgs boson with a top-quark pair,” *JHEP* **09** (2014) 087, [arXiv:1408.1682 \[hep-ex\]](#).
[Erratum: *JHEP*10,106(2014)].
- [7] **ATLAS** Collaboration, G. Aad *et al.*, “Search for supersymmetry at $\sqrt{s}=8$ TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector,” *JHEP* **06** (2014) 035, [arXiv:1404.2500 \[hep-ex\]](#).
- [8] **CMS** Collaboration, S. Chatrchyan *et al.*, “Search for new physics in events with same-sign dileptons and jets in pp collisions at $\sqrt{s} = 8$ TeV,” *JHEP* **01** (2014) 163, [arXiv:1311.6736](#). [Erratum: *JHEP*01,014(2015)].
- [9] **ATLAS** Collaboration, G. Aad *et al.*, “Measurement of the $t\bar{t}W$ and $t\bar{t}Z$ production cross sections in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector,” *JHEP* **11** (2015) 172, [arXiv:1509.05276 \[hep-ex\]](#).
- [10] **CMS** Collaboration, V. Khachatryan *et al.*, “Observation of top quark pairs produced in association with a vector boson in pp collisions at $\sqrt{s} = 8$ TeV,” *JHEP* **01** (2016) 096, [arXiv:1510.01131 \[hep-ex\]](#).
- [11] **ATLAS** Collaboration, G. Aad *et al.*, “Analysis of events with b -jets and a pair of leptons of the same charge in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector,” *JHEP* **10** (2015) 150, [arXiv:1504.04605 \[hep-ex\]](#).
- [12] **CMS** Collaboration, S. Chatrchyan *et al.*, “Search for top-quark partners with charge 5/3 in the same-sign dilepton final state,” *Phys. Rev. Lett.* **112** no. 17, (2014) 171801, [arXiv:1312.2391 \[hep-ex\]](#).
- [13] **ATLAS** Collaboration, G. Aad *et al.*, “Search for supersymmetry at $\sqrt{s} = 13$ TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector,” [arXiv:1602.09058 \[hep-ex\]](#).
- [14] **ATLAS** Collaboration, ATLAS-CONF-2016-003, “Measurement of the $t\bar{t}Z$ and $t\bar{t}W$ production cross sections in multilepton final states using 3.2 fb^{-1} of pp collisions at 13 TeV at the LHC,”.
- [15] **CMS** Collaboration, PAS-HIG-15-008, “Search for $t\bar{t}H$ production in multilepton final states at $\sqrt{s} = 13$ TeV,”.
- [16] **CMS** Collaboration, CMS-PAS-B2G-15-006, “Search for top quark partners with charge 5/3 at $\sqrt{s} = 13$ TeV,”.

- [17] <http://www.slac.stanford.edu/~barlow/java/statistics5.html>.
- [18] R. Barlow, “Asymmetric statistical errors,” in *Statistical problems in particle physics, astrophysics and cosmology. Proceedings, Conference, PHYSTAT05, Oxford, UK, September 12-15, 2005*, pp. 56–59. 2004. [arXiv:physics/0406120](#) [physics].
- [19] A. Angelescu, A. Djouadi, and G. Moreau, “Vector-like top/bottom quark partners and Higgs physics at the LHC,” *Eur. Phys. J.* **C76** no. 2, (2016) 99, [arXiv:1510.07527](#) [hep-ph].
- [20] M. Badziak and C. E. M. Wagner, “Enhancing the Higgs associated production with a top quark pair,” [arXiv:1602.06198](#) [hep-ph].
- [21] **ATLAS** Collaboration, ATLAS-CONF-2015-081, “Search for resonances decaying to photon pairs in 3.2 fb^{-1} of pp collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector,”.
- [22] **CMS** Collaboration, CMS-PAS-EXO-15-004, “Search for new physics in high mass diphoton events in proton-proton collisions at 13TeV ,”.
- [23] **ATLAS** Collaboration, ATLAS-CONF-2016-018, “Search for resonances in diphoton events with the ATLAS detector at $\sqrt{s} = 13 \text{ TeV}$,”.
- [24] **ATLAS** Collaboration, G. Aad *et al.*, “Search for high-mass diphoton resonances in pp collisions at $\sqrt{s} = 8 \text{ TeV}$ with the ATLAS detector,” *Phys. Rev.* **D92** no. 3, (2015) 032004, [arXiv:1504.05511](#) [hep-ex].
- [25] A. Djouadi, “The Anatomy of electro-weak symmetry breaking. I: The Higgs boson in the standard model,” *Phys. Rept.* **457** (2008) 1–216, [arXiv:hep-ph/0503172](#) [hep-ph].
- [26] A. Angelescu, A. Djouadi, and G. Moreau, “Scenarii for interpretations of the LHC diphoton excess: two Higgs doublets and vector-like quarks and leptons,” *Phys. Lett.* **B756** (2016) 126–132, [arXiv:1512.04921](#) [hep-ph].
- [27] S. Knapen, T. Melia, M. Papucci, and K. Zurek, “Rays of light from the LHC,” *Phys. Rev.* **D93** no. 7, (2016) 075020, [arXiv:1512.04928](#) [hep-ph].
- [28] D. Buttazzo, A. Greljo, and D. Marzocca, “Knocking on new physics door with a scalar resonance,” *Eur. Phys. J.* **C76** no. 3, (2016) 116, [arXiv:1512.04929](#) [hep-ph].
- [29] A. Pilaftsis, “Diphoton Signatures from Heavy Axion Decays at the CERN Large Hadron Collider,” *Phys. Rev.* **D93** no. 1, (2016) 015017, [arXiv:1512.04931](#) [hep-ph].
- [30] R. Franceschini, G. F. Giudice, J. F. Kamenik, M. McCullough, A. Pomarol, R. Rattazzi, M. Redi, F. Riva, A. Strumia, and R. Torre, “What is the $\gamma\gamma$ resonance at 750 GeV ?,”

- JHEP* **03** (2016) 144, [arXiv:1512.04933 \[hep-ph\]](#).
- [31] S. D. McDermott, P. Meade, and H. Ramani, “Singlet Scalar Resonances and the Diphoton Excess,” *Phys. Lett.* **B755** (2016) 353–357, [arXiv:1512.05326 \[hep-ph\]](#).
 - [32] J. Ellis, S. A. R. Ellis, J. Quevillon, V. Sanz, and T. You, “On the Interpretation of a Possible ~ 750 GeV Particle Decaying into $\gamma\gamma$,” *JHEP* **03** (2016) 176, [arXiv:1512.05327 \[hep-ph\]](#).
 - [33] R. S. Gupta, S. Jäger, Y. Kats, G. Perez, and E. Stamou, “Interpreting a 750 GeV Diphoton Resonance,” [arXiv:1512.05332 \[hep-ph\]](#).
 - [34] E. Molinaro, F. Sannino, and N. Vignaroli, “Minimal Composite Dynamics versus Axion Origin of the Diphoton excess,” [arXiv:1512.05334 \[hep-ph\]](#).
 - [35] B. Dutta, Y. Gao, T. Ghosh, I. Gogoladze, and T. Li, “Interpretation of the diphoton excess at CMS and ATLAS,” *Phys. Rev.* **D93** no. 5, (2016) 055032, [arXiv:1512.05439 \[hep-ph\]](#).
 - [36] A. Kobakhidze, F. Wang, L. Wu, J. M. Yang, and M. Zhang, “750 GeV diphoton resonance in a top and bottom seesaw model,” *Phys. Lett.* **B757** (2016) 92–96, [arXiv:1512.05585 \[hep-ph\]](#).
 - [37] R. Martinez, F. Ochoa, and C. F. Sierra, “Diphoton decay for a 750 GeV scalar boson in an $U(1)'$ model,” [arXiv:1512.05617 \[hep-ph\]](#).
 - [38] W. Chao, R. Huo, and J.-H. Yu, “The Minimal Scalar-Stealth Top Interpretation of the Diphoton Excess,” [arXiv:1512.05738 \[hep-ph\]](#).
 - [39] J. Chakraborty, A. Choudhury, P. Ghosh, S. Mondal, and T. Srivastava, “Di-photon resonance around 750 GeV: shedding light on the theory underneath,” [arXiv:1512.05767 \[hep-ph\]](#).
 - [40] P. Agrawal, J. Fan, B. Heidenreich, M. Reece, and M. Strassler, “Experimental Considerations Motivated by the Diphoton Excess at the LHC,” [arXiv:1512.05775 \[hep-ph\]](#).
 - [41] A. Falkowski, O. Slone, and T. Volansky, “Phenomenology of a 750 GeV Singlet,” *JHEP* **02** (2016) 152, [arXiv:1512.05777 \[hep-ph\]](#).
 - [42] D. Aloni, K. Blum, A. Dery, A. Efrati, and Y. Nir, “On a possible large width 750 GeV diphoton resonance at ATLAS and CMS,” [arXiv:1512.05778 \[hep-ph\]](#).
 - [43] R. Benbrik, C.-H. Chen, and T. Nomura, “Higgs singlet boson as a diphoton resonance in a vectorlike quark model,” *Phys. Rev.* **D93** no. 5, (2016) 055034, [arXiv:1512.06028](#)

- [hep-ph].
- [44] W. Chao, “Symmetries Behind the 750 GeV Diphoton Excess,” [arXiv:1512.06297](#) [hep-ph].
- [45] I. Chakraborty and A. Kundu, “Diphoton excess at 750 GeV: Singlet scalars confront triviality,” *Phys. Rev.* **D93** no. 5, (2016) 055003, [arXiv:1512.06508](#) [hep-ph].
- [46] H. Han, S. Wang, and S. Zheng, “Scalar Explanation of Diphoton Excess at LHC,” *Nucl. Phys.* **B907** (2016) 180–186, [arXiv:1512.06562](#) [hep-ph].
- [47] T.-F. Feng, X.-Q. Li, H.-B. Zhang, and S.-M. Zhao, “The LHC 750 GeV diphoton excess in supersymmetry with gauged baryon and lepton numbers,” [arXiv:1512.06696](#) [hep-ph].
- [48] O. Antipin, M. Mojaza, and F. Sannino, “A natural Coleman-Weinberg theory explains the diphoton excess,” [arXiv:1512.06708](#) [hep-ph].
- [49] F. Wang, L. Wu, J. M. Yang, and M. Zhang, “750 GeV Diphoton Resonance, 125 GeV Higgs and Muon $g-2$ Anomaly in Deflected Anomaly Mediation SUSY Breaking Scenario,” [arXiv:1512.06715](#) [hep-ph].
- [50] M. Dhuria and G. Goswami, “Perturbativity, vacuum stability and inflation in the light of 750 GeV diphoton excess,” [arXiv:1512.06782](#) [hep-ph].
- [51] S. M. Boucenna, S. Morisi, and A. Vicente, “The LHC diphoton resonance from gauge symmetry,” [arXiv:1512.06878](#) [hep-ph].
- [52] A. E. C. Hernández and I. Nisandzic, “LHC diphoton 750 GeV resonance as an indication of $SU(3)_c \times SU(3)_L \times U(1)_X$ gauge symmetry,” [arXiv:1512.07165](#) [hep-ph].
- [53] U. K. Dey, S. Mohanty, and G. Tomar, “750 GeV resonance in the dark leftright model,” *Phys. Lett.* **B756** (2016) 384–389, [arXiv:1512.07212](#) [hep-ph].
- [54] G. M. Pelaggi, A. Strumia, and E. Vigiani, “Trinification can explain the di-photon and di-boson LHC anomalies,” *JHEP* **03** (2016) 025, [arXiv:1512.07225](#) [hep-ph].
- [55] W.-C. Huang, Y.-L. S. Tsai, and T.-C. Yuan, “Gauged Two Higgs Doublet Model confronts the LHC 750 GeV di-photon anomaly,” [arXiv:1512.07268](#) [hep-ph].
- [56] K. M. Patel and P. Sharma, “Interpreting 750 GeV diphoton excess in $SU(5)$ grand unified theory,” *Phys. Lett.* **B757** (2016) 282–288, [arXiv:1512.07468](#) [hep-ph].
- [57] M. Badziak, “Interpreting the 750 GeV diphoton excess in minimal extensions of Two-Higgs-Doublet models,” [arXiv:1512.07497](#) [hep-ph].
- [58] Q.-H. Cao, S.-L. Chen, and P.-H. Gu, “Strong CP Problem, Neutrino Masses and the 750

- GeV Diphoton Resonance,” [arXiv:1512.07541 \[hep-ph\]](#).
- [59] W. Altmannshofer, J. Galloway, S. Gori, A. L. Kagan, A. Martin, and J. Zupan, “On the 750 GeV di-photon excess,” [arXiv:1512.07616 \[hep-ph\]](#).
 - [60] M. Cveti, J. Halverson, and P. Langacker, “String Consistency, Heavy Exotics, and the 750 GeV Diphoton Excess at the LHC,” [arXiv:1512.07622 \[hep-ph\]](#).
 - [61] J. Gu and Z. Liu, “Physics implications of the diphoton excess from the perspective of renormalization group flow,” *Phys. Rev.* **D93** no. 7, (2016) 075006, [arXiv:1512.07624 \[hep-ph\]](#).
 - [62] N. Craig, P. Draper, C. Kilic, and S. Thomas, “Shedding Light on Diphoton Resonances,” [arXiv:1512.07733 \[hep-ph\]](#).
 - [63] K. Das and S. K. Rai, “The 750 GeV Diphoton excess in a $U(1)$ hidden symmetry model,” [arXiv:1512.07789 \[hep-ph\]](#).
 - [64] K. Cheung, P. Ko, J. S. Lee, J. Park, and P.-Y. Tseng, “A Higgscision study on the 750 GeV Di-photon Resonance and 125 GeV SM Higgs boson with the Higgs-Singlet Mixing,” [arXiv:1512.07853 \[hep-ph\]](#).
 - [65] J. Zhang and S. Zhou, “Electroweak Vacuum Stability and Diphoton Excess at 750 GeV,” [arXiv:1512.07889 \[hep-ph\]](#).
 - [66] L. J. Hall, K. Harigaya, and Y. Nomura, “750 GeV Diphotons: Implications for Supersymmetric Unification,” *JHEP* **03** (2016) 017, [arXiv:1512.07904 \[hep-ph\]](#).
 - [67] H. Han, S. Wang, and S. Zheng, “Dark Matter Theories in the Light of Diphoton Excess,” [arXiv:1512.07992 \[hep-ph\]](#).
 - [68] A. Salvio and A. Mazumdar, “Higgs Stability and the 750 GeV Diphoton Excess,” *Phys. Lett.* **B755** (2016) 469–474, [arXiv:1512.08184 \[hep-ph\]](#).
 - [69] G. Li, Y.-n. Mao, Y.-L. Tang, C. Zhang, Y. Zhou, and S.-h. Zhu, “Pseudoscalar Decaying Only via Loops as an Explanation for the 750 GeV Diphoton Excess,” *Phys. Rev. Lett.* **116** no. 15, (2016) 151803, [arXiv:1512.08255 \[hep-ph\]](#).
 - [70] M. Son and A. Urbano, “A new scalar resonance at 750 GeV: Towards a proof of concept in favor of strongly interacting theories,” [arXiv:1512.08307 \[hep-ph\]](#).
 - [71] Y.-L. Tang and S.-h. Zhu, “NMSSM extended with vector-like particles and the diphoton excess on the LHC,” [arXiv:1512.08323 \[hep-ph\]](#).
 - [72] J. Cao, L. Shang, W. Su, F. Wang, and Y. Zhang, “Interpreting The 750 GeV Diphoton

- Excess Within Topflavor Seesaw Model,” [arXiv:1512.08392 \[hep-ph\]](#).
- [73] F. Wang, W. Wang, L. Wu, J. M. Yang, and M. Zhang, “Interpreting 750 GeV diphoton resonance as degenerate Higgs bosons in NMSSM with vector-like particles,” [arXiv:1512.08434 \[hep-ph\]](#).
 - [74] C. Cai, Z.-H. Yu, and H.-H. Zhang, “The 750 GeV diphoton resonance as a singlet scalar in an extra dimensional model,” [arXiv:1512.08440 \[hep-ph\]](#).
 - [75] Q.-H. Cao, Y. Liu, K.-P. Xie, B. Yan, and D.-M. Zhang, “The Diphoton Excess, Low Energy Theorem and the 331 Model,” *Phys. Rev.* **D93** (2016) 075030, [arXiv:1512.08441 \[hep-ph\]](#).
 - [76] F. Goertz, J. F. Kamenik, A. Katz, and M. Nardecchia, “Indirect Constraints on the Scalar Di-Photon Resonance at the LHC,” [arXiv:1512.08500 \[hep-ph\]](#).
 - [77] P. S. B. Dev, R. N. Mohapatra, and Y. Zhang, “Quark Seesaw, Vectorlike Fermions and Diphoton Excess,” *JHEP* **02** (2016) 186, [arXiv:1512.08507 \[hep-ph\]](#).
 - [78] N. Bizot, S. Davidson, M. Frigerio, and J. L. Kneur, “Two Higgs doublets to explain the excesses $pp \rightarrow \gamma\gamma(750 \text{ GeV})$ and $h \rightarrow \tau^\pm \mu^\mp$,” *JHEP* **03** (2016) 073, [arXiv:1512.08508 \[hep-ph\]](#).
 - [79] S. K. Kang and J. Song, “Top-phobic heavy Higgs boson as the 750 GeV diphoton resonance,” [arXiv:1512.08963 \[hep-ph\]](#).
 - [80] I. Low and J. Lykken, “Implications of Gauge Invariance on a Heavy Diphoton Resonance,” [arXiv:1512.09089 \[hep-ph\]](#).
 - [81] A. E. C. Hernández, “The 750 GeV diphoton resonance can cause the SM fermion mass and mixing pattern,” [arXiv:1512.09092 \[hep-ph\]](#).
 - [82] Y. Jiang, Y.-Y. Li, and T. Liu, “750 GeV Resonance in the Gauged $U(1)'$ -Extended MSSM,” [arXiv:1512.09127 \[hep-ph\]](#).
 - [83] S. Jung, J. Song, and Y. W. Yoon, “How Resonance-Continuum Interference Changes 750 GeV Diphoton Excess: Signal Enhancement and Peak Shift,” [arXiv:1601.00006 \[hep-ph\]](#).
 - [84] E. Palti, “Vector-Like Exotics in F-Theory and 750 GeV Diphotons,” [arXiv:1601.00285 \[hep-ph\]](#).
 - [85] P. Ko, Y. Omura, and C. Yu, “Diphoton Excess at 750 GeV in leptophobic $U(1)'$ model inspired by E_6 GUT,” *JHEP* **04** (2016) 098, [arXiv:1601.00586 \[hep-ph\]](#).

- [86] W. Chao, “The Diphoton Excess from an Exceptional Supersymmetric Standard Model,” [arXiv:1601.00633 \[hep-ph\]](#).
- [87] A. Karozas, S. F. King, G. K. Leontaris, and A. K. Meadowcroft, “750 GeV diphoton excess from E_6 in F-theory GUTs,” *Phys. Lett.* **B757** (2016) 73–78, [arXiv:1601.00640 \[hep-ph\]](#).
- [88] A. E. C. Hernández, I. d. M. Varzielas, and E. Schumacher, “The 750 GeV diphoton resonance in the light of a 2HDM with S_3 flavour symmetry,” [arXiv:1601.00661 \[hep-ph\]](#).
- [89] T. Modak, S. Sadhukhan, and R. Srivastava, “750 GeV diphoton excess from gauged $B - L$ symmetry,” *Phys. Lett.* **B756** (2016) 405–412, [arXiv:1601.00836 \[hep-ph\]](#).
- [90] B. Dutta, Y. Gao, T. Ghosh, I. Gogoladze, T. Li, Q. Shafi, and J. W. Walker, “Diphoton Excess in Consistent Supersymmetric SU(5) Models with Vector-like Particles,” [arXiv:1601.00866 \[hep-ph\]](#).
- [91] F. F. Deppisch, C. Hati, S. Patra, P. Pritimita, and U. Sarkar, “Implications of the diphoton excess on leftright models and gauge unification,” *Phys. Lett.* **B757** (2016) 223–230, [arXiv:1601.00952 \[hep-ph\]](#).
- [92] S. Bhattacharya, S. Patra, N. Sahoo, and N. Sahu, “750 GeV Di-Photon Excess at CERN LHC from a Dark Sector Assisted Scalar Decay,” [arXiv:1601.01569 \[hep-ph\]](#).
- [93] P. Ko and T. Nomura, “Dark sector shining through 750 GeV dark Higgs boson at the LHC,” [arXiv:1601.02490 \[hep-ph\]](#).
- [94] J. Cao, L. Shang, W. Su, Y. Zhang, and J. Zhu, “Interpreting the 750 GeV diphoton excess in the Minimal Dilaton Model,” [arXiv:1601.02570 \[hep-ph\]](#).
- [95] J.-H. Yu, “Hidden Gauged U(1) Model: Unifying Scotogenic Neutrino and Flavor Dark Matter,” [arXiv:1601.02609 \[hep-ph\]](#).
- [96] R. Ding, Z.-L. Han, Y. Liao, and X.-D. Ma, “Interpretation of 750 GeV Diphoton Excess at LHC in Singlet Extension of Color-octet Neutrino Mass Model,” *Eur. Phys. J.* **C76** no. 4, (2016) 204, [arXiv:1601.02714 \[hep-ph\]](#).
- [97] A. E. Faraggi and J. Rizos, “The 750 GeV di-photon LHC excess and extra Z' s in heterotic-string derived models,” *Eur. Phys. J.* **C76** no. 3, (2016) 170, [arXiv:1601.03604 \[hep-ph\]](#).
- [98] X.-F. Han, L. Wang, and J. M. Yang, “An extension of two-Higgs-doublet model and the

- excesses of 750 GeV diphoton, muon g-2 and $h \rightarrow \mu\tau$,” [arXiv:1601.04954 \[hep-ph\]](#).
- [99] S. F. King and R. Nevzorov, “750 GeV Diphoton Resonance from Singlets in an Exceptional Supersymmetric Standard Model,” *JHEP* **03** (2016) 139, [arXiv:1601.07242 \[hep-ph\]](#).
 - [100] E. Bertuzzo, P. A. N. Machado, and M. Taoso, “Di-Photon excess in the 2HDM: hastening towards the instability and the non-perturbative regime,” [arXiv:1601.07508 \[hep-ph\]](#).
 - [101] A. Salvio, F. Staub, A. Strumia, and A. Urbano, “On the maximal diphoton width,” *JHEP* **03** (2016) 214, [arXiv:1602.01460 \[hep-ph\]](#).
 - [102] S.-F. Ge, H.-J. He, J. Ren, and Z.-Z. Xianyu, “Realizing Dark Matter and Higgs Inflation in Light of LHC Diphoton Excess,” [arXiv:1602.01801 \[hep-ph\]](#).
 - [103] S. I. Godunov, A. N. Rozanov, M. I. Vysotsky, and E. V. Zhemchugov, “New Physics at 1 TeV?,” [arXiv:1602.02380 \[hep-ph\]](#).
 - [104] C. Arbeláez, A. E. C. Hernández, S. Kovalenko, and I. Schmidt, “Linking radiative seesaw-type mechanism of fermion masses and non-trivial quark mixing with the 750 GeV diphoton excess,” [arXiv:1602.03607 \[hep-ph\]](#).
 - [105] C. Gross, O. Lebedev, and J. M. No, “Drell-Yan Constraints on New Electroweak States and the Di-photon Anomaly,” [arXiv:1602.03877 \[hep-ph\]](#).
 - [106] C. Han, T. T. Yanagida, and N. Yokozaki, “Implications of the 750 GeV Diphoton Excess in Gaugino Mediation,” *Phys. Rev.* **D93** no. 5, (2016) 055025, [arXiv:1602.04204 \[hep-ph\]](#).
 - [107] F. Staub *et al.*, “Precision tools and models to narrow in on the 750 GeV diphoton resonance,” [arXiv:1602.05581 \[hep-ph\]](#).
 - [108] M. Cvetič, J. Halverson, and P. Langacker, “String Consistency, Heavy Exotics, and the 750 GeV Diphoton Excess at the LHC: Addendum,” [arXiv:1602.06257 \[hep-ph\]](#).
 - [109] J. Ren and J.-H. Yu, “SU(2) x SU(2) x U(1) Interpretation on the 750 GeV Diphoton Excess,” [arXiv:1602.07708 \[hep-ph\]](#).
 - [110] C.-W. Chiang, H. Fukuda, M. Ibe, and T. T. Yanagida, “750 GeV diphoton resonance in a visible heavy QCD axion model,” [arXiv:1602.07909 \[hep-ph\]](#).
 - [111] G. Lazarides and Q. Shafi, “Diphoton Resonances in U(1)_{B-L} Extension of MSSM,” [arXiv:1602.07866 \[hep-ph\]](#).
 - [112] C. Bonilla, M. Nebot, R. Srivastava, and J. W. F. Valle, “A flavour physics scenario for the 750 GeV diphoton anomaly,” *Phys. Rev.* **D93** (2016) 073009, [arXiv:1602.08092 \[hep-ph\]](#).

- [113] T. Li, J. A. Maxin, V. E. Mayes, and D. V. Nanopoulos, “The 750 GeV Diphoton Excesses in a Realistic D-brane Model,” [arXiv:1602.09099 \[hep-ph\]](#).
- [114] R. Barbieri, D. Buttazzo, L. J. Hall, and D. Marzocca, “Higgs mass and unified gauge coupling in the NMSSM with Vector Matter,” [arXiv:1603.00718 \[hep-ph\]](#).
- [115] G. Bélanger and C. Delaunay, “A Dark Sector for $g_\mu - 2$, R_K and a Diphoton Resonance,” [arXiv:1603.03333 \[hep-ph\]](#).
- [116] M. Perelstein and Y.-D. Tsai, “750 GeV Di-photon Excess and Strongly First-Order Electroweak Phase Transition,” [arXiv:1603.04488 \[hep-ph\]](#).
- [117] S. Fraser, C. Kownacki, E. Ma, N. Pollard, O. Popov, and M. Zakeri, “Phenomenology of the Utilitarian Supersymmetric Standard Model,” [arXiv:1603.04778 \[hep-ph\]](#).
- [118] D. T. Huong and P. V. Dong, “Left-right asymmetry and 750 GeV diphoton excess,” [arXiv:1603.05146 \[hep-ph\]](#).
- [119] G. K. Leontaris and Q. Shafi, “Diphoton Resonance in F-theory inspired Flipped SO(10),” [arXiv:1603.06962 \[hep-ph\]](#).
- [120] S. Di Chiara, A. Hektor, K. Kannike, L. Marzola, and M. Raidal, “Large loop-coupling enhancement of a 750 GeV pseudoscalar from a light dark sector,” [arXiv:1603.07263 \[hep-ph\]](#).
- [121] C. Csaki and L. Randall, “A Diphoton Resonance from Bulk RS,” [arXiv:1603.07303 \[hep-ph\]](#).
- [122] N. Liu, W. Wang, M. Zhang, and R. Zheng, “750 GeV Diphoton Resonance in a Vector-like Extension of Hill Model,” [arXiv:1604.00728 \[hep-ph\]](#).
- [123] T. Gherghetta, N. Nagata, and M. Shifman, “A Visible QCD Axion from an Enlarged Color Group,” [arXiv:1604.01127 \[hep-ph\]](#).
- [124] H. P. Nilles and M. W. Winkler, “750 GeV Diphotons and Supersymmetric Grand Unification,” [arXiv:1604.03598 \[hep-ph\]](#).
- [125] M. Duerr, P. F. Perez, and J. Smirnov, “New Forces and the 750 GeV Resonance,” [arXiv:1604.05319 \[hep-ph\]](#).
- [126] S. Gopalakrishna and T. S. Mukherjee, “The 750 GeV diphoton excess in a two Higgs doublet model and a singlet scalar model, with vector-like fermions, unitarity constraints, and dark matter implications,” [arXiv:1604.05774 \[hep-ph\]](#).
- [127] S. Chang, “A Simple $U(1)$ Gauge Theory Explanation of the Diphoton Excess,” *Phys. Rev.*

- D93** no. 5, (2016) 055016, [arXiv:1512.06426 \[hep-ph\]](#).
- [128] A. Djouadi, J. Ellis, R. Godbole, and J. Quevillon, “Future Collider Signatures of the Possible 750 GeV State,” *JHEP* **03** (2016) 205, [arXiv:1601.03696 \[hep-ph\]](#).
 - [129] J. Kawamura and Y. Omura, “Diphoton excess at 750 GeV and LHC constraints in models with vector-like particles,” [arXiv:1601.07396 \[hep-ph\]](#).
 - [130] Y. Hamada, H. Kawai, K. Kawana, and K. Tsumura, “Models of LHC Diphoton Excesses Valid up to the Planck scale,” [arXiv:1602.04170 \[hep-ph\]](#).
 - [131] K. J. Bae, M. Endo, K. Hamaguchi, and T. Moroi, “Diphoton Excess and Running Couplings,” [arXiv:1602.03653 \[hep-ph\]](#).
 - [132] Y. Hamada, T. Noumi, S. Sun, and G. Shiu, “An O(750) GeV Resonance and Inflation,” [arXiv:1512.08984 \[hep-ph\]](#).
 - [133] H.-C. Cheng, I. Low, and L.-T. Wang, “Top partners in little Higgs theories with T-parity,” *Phys. Rev.* **D74** (2006) 055001, [arXiv:hep-ph/0510225 \[hep-ph\]](#).
 - [134] R. Contino and G. Servant, “Discovering the top partners at the LHC using same-sign dilepton final states,” *JHEP* **06** (2008) 026, [arXiv:0801.1679 \[hep-ph\]](#).
 - [135] A. D. Martin, W. J. Stirling, R. S. Thorne, and G. Watt, “Parton distributions for the LHC,” *Eur. Phys. J.* **C63** (2009) 189–285, [arXiv:0901.0002 \[hep-ph\]](#).
 - [136] A. Djouadi, “The Anatomy of electro-weak symmetry breaking. II. The Higgs bosons in the minimal supersymmetric model,” *Phys. Rept.* **459** (2008) 1–241, [arXiv:hep-ph/0503173 \[hep-ph\]](#).
 - [137] **ATLAS** Collaboration, M. Aaboud *et al.*, “Search for metastable heavy charged particles with large ionization energy loss in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS experiment,” [arXiv:1604.04520 \[hep-ex\]](#).
 - [138] A. Alloul, N. D. Christensen, C. Degrande, C. Duhr, and B. Fuks, “FeynRules 2.0 - A complete toolbox for tree-level phenomenology,” *Comput. Phys. Commun.* **185** (2014) 2250–2300, [arXiv:1310.1921 \[hep-ph\]](#).
 - [139] G. Bélanger, F. Boudjema, A. Pukhov, and A. Semenov, “micrOMEGAs4.1: two dark matter candidates,” *Comput. Phys. Commun.* **192** (2015) 322–329, [arXiv:1407.6129 \[hep-ph\]](#).
 - [140] **ATLAS** Collaboration, G. Aad *et al.*, “Search for vector-like B quarks in events with one isolated lepton, missing transverse momentum and jets at $\sqrt{s} = 8$ TeV with the ATLAS

- detector,” *Phys. Rev.* **D91** no. 11, (2015) 112011, [arXiv:1503.05425 \[hep-ex\]](#).
- [141] **CMS** Collaboration, V. Khachatryan *et al.*, “Search for vector-like charge 2/3 T quarks in proton-proton collisions at $\sqrt{s} = 8$ TeV,” *Phys. Rev.* **D93** no. 1, (2016) 012003, [arXiv:1509.04177 \[hep-ex\]](#).
- [142] **ATLAS** Collaboration, G. Aad *et al.*, “ATLAS Run 1 searches for direct pair production of third-generation squarks at the Large Hadron Collider,” *Eur. Phys. J.* **C75** no. 10, (2015) 510, [arXiv:1506.08616 \[hep-ex\]](#). [Erratum: *Eur. Phys. J.* **C76**,no.3,153(2016)].
- [143] **ATLAS** Collaboration, ATLAS-CONF-2016-007, “Search for top squarks in final states with one isolated lepton, jets, and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions of ATLAS data,”.
- [144] **CMS** Collaboration, V. Khachatryan *et al.*, “Search for direct pair production of scalar top quarks in the single- and dilepton channels in proton-proton collisions at $\sqrt{s} = 8$ TeV,” *Submitted to: JHEP* (2016) , [arXiv:1602.03169 \[hep-ex\]](#).
- [145] **CMS** Collaboration, CMS-PAS-SUS-16-002, “Search for direct top squark pair production in the single lepton final state at $\sqrt{s} = 13$ TeV,”.
- [146] J. Alwall, P. Demin, S. de Visscher, R. Frederix, M. Herquet, F. Maltoni, T. Plehn, D. L. Rainwater, and T. Stelzer, “MadGraph/MadEvent v4: The New Web Generation,” *JHEP* **09** (2007) 028, [arXiv:0706.2334 \[hep-ph\]](#).
- [147] T. Sjostrand, S. Mrenna, and P. Z. Skands, “PYTHIA 6.4 Physics and Manual,” *JHEP* **05** (2006) 026, [arXiv:hep-ph/0603175 \[hep-ph\]](#).
- [148] **DELPHES 3** Collaboration, J. de Favereau, C. Delaere, P. Demin, A. Giammanco, V. Lematre, A. Mertens, and M. Selvaggi, “DELPHES 3, A modular framework for fast simulation of a generic collider experiment,” *JHEP* **02** (2014) 057, [arXiv:1307.6346 \[hep-ex\]](#).